DEMONSTRATION OF THE LIFTING POWER OF EVAPORATION.

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The lifting power of evaporation and the liquid tension present in water are two important forces in the transpiration stream. The desirability of having a better conception of these forces has led to numerous experiments. A modified Askenasy experiment has proven quite successful in demonstrating these forces in moving materials. A clearer picture can thus be impressed upon the minds of students in botany by actual demonstration.

An attempt was made first to perform the experiment using such materials as are usually available in a general botany laboratory and second to make the demonstration less cumbersome and more successful. The results obtained with the apparatus described in this paper have shown that with a relative degree of precaution, these two forces can be demonstrated in every laboratory.

Askenasy in 1896 fused a glass funnel on the upper end of a long glass tube. A layer of plaster of Paris was placed in the broad upper end of the funnel. After the plaster hardened the apparatus was filled with water and the end of the glass tube dipped in mercury. As the water evaporated from the plaster surface the mercury rose in the tube and attained a height of 82 cm. Ursprung (1913) used a porous porcelain cylinder as an evaporating surface. He improved considerably upon the technique and obtained much better results. However the demonstration was still quite unwieldy. A great improvement in the set up of the apparatus, as worked out by Lubin, is included in Livingston's 3rd edition of Palladin's Plant Physiology (1926).

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The apparatus used in these experiments was essentially the same as Lubin's arrangement, and with the few improvements made, is shown in the diagram (Fig. 1). The materials needed for the apparatus are: a porous porcelain cylinder or cup, a long J-shaped, thick walled, small bore glass tube, a bottle containing mercury, a large beaker, a source of heat such as a Bunsen burner, a vacuum pump and a one-hole and a two-hole rubber stopper.

In preparation for a demonstration, the apparatus was first thoroughly cleaned. The porous porcelain cylinder or cup (C) was filled with distilled water and attached by means of the one hole rubber stopper (D) to the short arm of the J-shaped vertical glass tube (E). The porcelain cylinder was then submerged in a beaker of water. The end of the long arm of the glass tube was fastened into the bottle containing the mercury by means of the two-hole rubber stopper (H) so that the end of the tube dipped below the surface of the mercury. The attachment for the suction pump (G) was fitted into the second hole of the rubber stopper.

After the apparatus had been assembled the water in the beaker was heated to boiling and by applying suction to the long arm of the J-shaped tube the hot water was caused to filter through the system. After the apparatus had been thoroughly washed and all undissolved air had been driven from the system by boiling it was allowed to cool to room temperature. By allowing the apparatus to stand, dissolved air could penetrate the entire system. Consequently tension was shown in water solutions containing dissolved air which no doubt is the condition of the water contained in the plant vessels and tissues. With the apparatus set in this manner, however, liquid tension could not be obtained. It was found necessary to substitute a colloidal coat for the evaporating surface of the porcelain cup. The coating used was a colloid such as agar agar or gelatin.

A colloid coat has two advantages: 1. A colloidal gel can be more easily duplicated than a porcelain surface and by coating several cylinders with the same colloidal gel, one can be sure of having relatively uniform evaporating surfaces on several cups. 2. Coating eliminates the difficulty encountered by former workers in finding porous porcelain cylinders that were sufficiently fine pored to support the air water menisci against several atmospheres of pressure. Some of the colloidal coats tend to

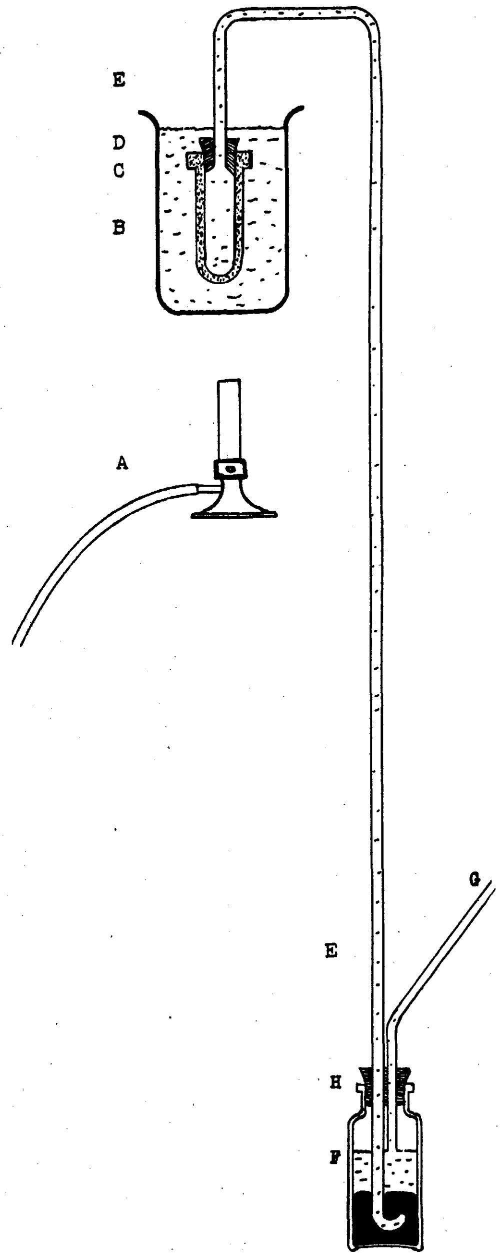

FIGURE 1

deteriorate or wash off when the cylinder is submerged in the beaker of water. A discussion of the characteristics of the various types of coats used will be included with the results.

The general method of applying the coat was as follows: the beaker was removed from around the porous cup and immediately 100 to 150 c.c. of the colloidal sol was poured over the rubber stopper and porous cup. Care was taken to see that the entire cup surface has been covered by the colloidal sol. A sufficient amount of the sol adhered to the cup to form an evaporation surface. When collodion (dissolved in alcohol and ether) was used as the colloidal sol it was found necessary to first wipe off all excess water from the surface of the cup.

The suction pump should be detached before allowing evaporation to take place. The evaporation of the water from the cup caused a decrease of water volume and this decrease of volume was compensated by the drawing of the mercury up into the glass tube. This process continued until a break occurred somewhere in the water or mercury column. Most of the breaks occurred in the water column. As soon as a break or bubble occurred the level of the mercury, if it was above atmospheric pressure, dropped to a level corresponding to nearly atmospheric pressure.

All that was necessary for a second trial was to submerge the porous cup in the beaker of water and the infiltrating water would force the bubble from the system. Applying suction to the long arm of the glass tube hastened the process. Cutting the lower surface of the one-hole rubber stopper so that it tapers toward the glass tube and bending the tip of the long arm of the glass tube, as shown in the diagram, often aided greatly in the removal of bubbles. After the bubble was removed, the suction pump was detached and the porous cup exposed to the air. Air currents from an electric fan hastened the evaporation process.

The time required to run a demonstration could be divided into two parts, first the cleaning and boiling of the apparatus and second the running of a trial. An hour of boiling the water in the beaker, simultaneously applying suction, has been found sufficient to remove all undissolved air. The apparatus was then allowed to cool to room temperature. The apparatus may be boiled a day or two previous to a trial, thus saving time. The time required for a trial after the coat has been applied varied from ten minutes to several hours depending upon the bore of the glass tube, the consistency of the colloidal coat applied, the humidity and movement of the air and the height reached in the trial. Ten to twenty-five minutes were required to attain a height of 100 to 150 cm. in a one m.m. tube when a 20% gelatin coat was used.

The results or heights given have been corrected by the following formula:

$$H = h + c + \frac{W_1 - W_2}{13.6}$$

H = Total height of mercury column.
h = Ht. of mercury meniscus in tube above the mercury level in the bottle.
c = Correction for mercury depression in glass tube.
W_1 = Height of water column from the mercury meniscus to the top of the glass tube.
W_2 = Height of water standing above mercury in bottle.

By subtracting the atmospheric pressure from the total height (H) one has the height in terms of mercury that was supported by the cohesion or liquid tension of the water column.

Gelatin, agar agar, gum arabic, tragacanth, Karo syrup and collodion were used as evaporating surfaces. Sols of the first four were prepared by placing a definite number of grams of the dry granular substance in 100 c.c. of water and then heating to boiling in a water bath. These sols are referred to later as percentage sols. They were applied to the porous cups soon after being removed from the water bath and thus had a temperature of 90–98°C when applied. The Karo syrup and collodion were applied in the commercial form and at room temperature.

The following table gives some of the results. These results, excepting tragacanth, were obtained in glass tubing of 2 m.m. diameter. The trials were all made at room temperature 20 to 25°C.

Sol or Solution	Number of Trials	Average for Trials. Ht. in cm.	Highest Reading	
			Day of Trial	Ht. in cm.
20% Gelatin	41	129.1	Dec. 1	188.7
2% Agar Agar	22	120.4	Nov. 2	146.1
10% Gum Arabic	17	128.9	Nov. 30	168.4
5% Tragacanth (1 m. m. tube)	3	120.5	Mar. 7	130.6
Karo Syrup	2	111.4	Dec. 6	128.1
Collodion	6	91.8	Oct. 5	99.2

The sols or solutions were arranged in the table according to their practicability as far as it was possible to determine. A gelatin, agar agar or collodian coat could be used repeatedly as these coats did not wash off when immersed in water. The height efficiency of the collodion, however, placed it at the bottom of the list. Gum arabic, tragacanth and Karo syrup could be used as quite efficient evaporating surfaces for single trials. These coats however wash off when the porous cups were immersed in water in attempting to remove air bubbles from the system.

Gelatin seemed to offer the best type of coat. The following table gives the results obtained from a good 20% gelatin coat.

Cup boiled Nov. 29 (1–3 P. M.)
Cup coated Nov. 29 (8 P. M.)

Time, 1927	Total Ht. cm.	Barometer Ht. cm.	Ht. above Barometer
Nov. 29—8- 9 P. M....	96.6 (Fan)	74	22.6
Nov. 30—2- 3 P. M....	184.4 "	73.5	110.9
Nov. 30—7- 9 P. M....	167.2 "	73.7	93.5
Dec. 1—3- 4 P. M....	188.7 "	75.3	113.4
Dec. 1—7- 9 P. M....	93.6 (No Fan)	75.3	18.3
Dec. 2—2- 4 P. M....	179.8 (Fan)	74.6	105.2
Dec. 3—8- 9 A. M....	144.3 "	75.3	69
Dec. 4—9-10 A. M....	136.5 "	75	61.5
Dec. 5—3- 4 P. M....	132.2 "	74.5	57.7

The four highest records obtained by using gelatin are given in the following table. Data corrected to 25°C.

HEIGHT RECORDS.

	In 2 mm. Tube	Coat of 20% Gelatin	
Time, 1927	Total Ht. cm.	Barometer cm.	Ht. Above Barometer
Nov. 30...............	184.4	73.5	110.9
Dec. 1................	188.7	75.3	113.4
Dec. 2................	179.8	74.6	105.2
1928	In 1 mm. Tube	Coat of 25% Gelatin Sol	
Mar. 11...............	226.6	73.7	152.9

A gelatin coat tended to deteriorate but one coat was generally good for from five to ten trials, provided the trials were made within a week.

Summary.

The above experiments, with an improved Askenasy apparatus may be summarized as follows:

1. Liquid tension and the lifting power of evaporation can be demonstrated.
2. A colloidal coat was substituted as the evaporating surface of the porcelain cup.
3. Gelatin, agar agar, gum arabic, tragacanth, Karo syrup and collodion were used as evaporating surfaces.
4. With a relative degree of precaution, heights of mercury exceeding atmospheric pressure can be easily attained.
5. Gelatin seemed to afford the most satisfactory coating. It was easily applied and gave consistently high records. Out of 41 successive trials with 20% gelatin the average total rise of mercury was 129.1 cm. with a minimum of 81.9 cm. and a maximum of 188.7 cm.
6. The highest record, 226.6 cm., was attained by using a 25% gelatin coat.

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